Chapter 2
Empirical Studies in Information Sharing

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Abstract This chapter provides a non-technical literature survey of empirical studies in information sharing during the past two decades. We categorize by types of information that can be shared in a supply chain environment, such as demand, forecasts, inventory status, and product development. We encourage more empirical research to be done to further advance knowledge in this field.

2.1 Introduction

No supply chain can run smoothly without information. In this chapter, we provide a literature review related to sharing different types of information in a supply chain. We focus on empirical studies, however our definition of "empirical" is rather broad—any relevant work that involves collecting data is permissible. Hence it includes experimental work, surveys, and even case studies. Moreover, it is often necessary to discuss theoretical models as they serve as the motivation or guide for some empirical work. When that happens, we will do so briefly.

2.1.1 Types of Information in a Supply Chain

Think of a typical three-stage supply chain with a manufacturer, a distributor, and a retailer. Products flow from upstream (manufacturer) to downstream (end demand). But what really enables the supply chain is the flow of information. For example,

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demand information arrives at the retailer, who orders from its distribution channel, who in turn orders from the manufacturer. Without such information, the supply chain cannot do what it is supposed to do, which is to match supply with demand.

There could be many types of information being transmitted in a supply chain—which we categorize below—but a central question for each supply chain party is: What information is needed in order for it to optimize its operations?

We could categorize the main types of information that are explicit or implicit in the supply chain, somewhat in order of prevalence, as follows:

- *Demand.* Demand (or order information) is perhaps the most important type of information in a supply chain. It should come as no surprise because the reason supply chains exist is to match demand with supply. However, exactly how important is it to have accurate demand information? What can supply chain parties do if such information is not available? Those are some of the key supply chain research questions.
- *Forecasts.* Sometimes what was received from the downstream party or what was sent to its upstream party are not actual orders, but just order forecasts (or mere intention of orders) either in the form of a point estimate, or a statistical distribution ("probably x, but maybe y ..."). To what extent those forecasts are accurate (inaccurate, and why so) are then relevant questions. More importantly, do supply chain parties always share forecast information truthfully? Why or why not?
- *Inventory status information.* This includes order status information such as the quantity of inventory at each stage in the system. It may also include information about inventory availability at each stage of the system.
- *Product development information.* Companies follow very different practices in announcing products in development: Microsoft regularly announces what will be coming in the next few years, while Apple holds tight lips on what their next product (or even next versions of an existing product) will be. So an interesting question will be: Does it offer any benefit if a manufacturer shares its product development information with its downstream parties?
- *Information accuracy.* Most of the research in information sharing assumes that information existing in the supply chain is accurate (we distinguish inaccurate information from information generated from strategic information-sharing behavior). However, that is frequently not true in practice. Supply chain parties have to deal with inaccurate information. What if we know some information is subject to errors, and may be inaccurate?

This list is not exhaustive by any means, but here we focus on topics where substantive research has been done. Next, we briefly summarize major research themes in the literature that are related to information sharing in supply chains.

2.1.2 Key Questions for Empirical Research

Related to information and information sharing, there are a number of research questions that can be asked. The following is a partial list:

1. What is the value of having a certain type of information in a supply chain, such as demand forecast or order information?
2. What are the incentive issues in information sharing?
3. How can information be used in improving system efficiency?
4. How is the value of information changed by contracts, organizational factors of supply chain parties, and market structure?

We now review relevant empirical literature by each type of information categorized above.

2.2 Value of Demand Information

Over the past two decades, along with the increasing presence of information technology (IT), there has been increasing interest on studying the value of demand-related information in various supply chains. A significant body of theoretical knowledge has been built in this area.

Through various supply chain models, researchers have demonstrated that sharing information on demand will overall improve the efficiency of the whole system, though the exact magnitude of improvement vary depending on model specifics. Representative work include Chen (1998) (N-stage serial system with recorder policy; benefit ranges from 0 to 9 %), Gavirneni et al. (1999) (two-stage capacitated inventory system with (s,S) policy; costs decrease vary from 1 to 90 %), Lee et al. (2000) (two-stage serial supply chain with autoregressive demand), Gaur et al. (2005) (serial system autoregressive moving average demand), Aviv and Federgruen (1998) (Vendor Managed Inventory (VMI) program, cost saving from 2 to 4.7 %).

Do those theoretical improvement pan out in reality? So far as we know, there has been few empirical studies that aim to test directly the theoretical predictions put forth by the aforementioned papers (it will be very interesting if some future research aims to do just that). As far as we know, Zhou and Benton (2007) offer the closest alternative. The authors collected surveys from over a hundred companies asking about their practice on information sharing with their suppliers and their customers and the effectiveness of their information sharing practice. They consider three aspects of information sharing: information sharing support technology, information content, and information quality. The results are overall positive. For example, they find strong evidence that effective information sharing enhances effective supply chain practice.

Another stream of empirical research investigate the effectiveness and efficiency of such supply chain collaboration initiatives as EDI or VMI. Daugherty et al. (1999) survey executives of about 100 firms with an average annual revenue of $2.3 billion,

and find that VMI practices are positively correlated with firm performance. Kuk (2004) looks at the effect of organizational and supply chain factors such as employee involvement and supply chain integration on the effectiveness of VMI. Analyzing results from a survey in the electronics industry, the author finds that supply chain members with higher levels of employee involvement and logistics integration were more likely to realize the potential benefit of VMI. Moreover, it is also found that VMI seems to have benefited small organizations more than large ones.

2.3 Value of Advance Orders Information

Another class of demand information is advanced orders, or "pre-orders." Sometimes, customers are willing to wait for a certain length of time before receiving and consuming a product. This advance demand information should permit suppliers to better forecast demand and replenish inventory. Tang et al. (2004) documents the case of a large bakery in Hong Kong on the production of moon cake, a type of pastry that is consumed for the annual "mid-autumn festival" in many Asian cultures. The retailer can induce customers to pre-order for a discounted price before the selling season, which the authors call "Advance Book Discount" (ABD) program. The time between placement and fulfillment of these pre-committed orders provides an opportunity for the retailer to update demand forecasts. This paper, by demonstrating the benefit advance demand information, is rather prescient, because such a benefit is increasingly being realized in global commerce with the help of information technology. Fast forward to 2013, Alibaba (the world's largest e-commerce platform) has started such ABD program where Chinese consumers first place orders for produce products from US such as cherries and then wait for delivery.

Such advance order tactics are also routinely employed by consumer-goods manufacturers and retailers. Moe and Fader (2002) use actual advance sales and total sales data of music albums obtained from CDNOW to study the effectiveness of advance purchase orders on modeling total sales. They show that advance sales provide meaningful information in terms of better forecasting sales. With better demand information, cost savings and increased margins should follow. The distribution of the benefits will depends on the contracts between supply chain parties.

Fisher and Raman (1996) provides another anecdotal example in the apparel industry, and show that early orders indeed provide an important tool in forecasting sales and managing production and global supply chains.

For the apparel manufacturer in this study, demand for a particular item is highly unpredictable, and supply lead time is long. Initial forecasts of demand does not offer great help in terms of accurately managing supply, but by observing early orders the manufacturers are able to remarkably better allocate capacity to meet supply and therefore increase profitability. See Fig. 1 in Fisher and Raman (1996) at http://dx.doi.org/10.1287/opre.44.1.87, showing the value of early demand information (a) with no early demand information and (b) with early demand information. Even though in this example, early orders are technically different from advance orders in

that the former are sold while in stock, while the latter are sold before products are available, the idea is the same: Early demand signal serves as a powerful instrument in managing supply with demand.

2.4 Sharing Forecast Information

Forecast information is different from "real" information. Forecasts are, by definition, inaccurate. More often than not, forecasts represent forecasters' mere intentions to order, and are not contractible. Hence, incentives play a huge role in sharing forecast information.

With the increasing adoption of Material Requirement Planning (MRP) system and Enterprise Resource Planning (ERP) system in industries all over the world, incorporating demand forecasts into production and inventory management system is become more and more important. In this area, research has been quite fruitful.

As one of the earliest works in this area, Graves et al. (1998) developed a martingale model of forecast evolution model (MMFE) to study requirement planning in multistage production-inventory system. Motivated by an industry study, Heath and Jackson (1994) propose another MMFE model to characterize the process of forecast evolution, and apply this model in a simulation study to analyze safety stock levels for a production and distribution system. Later works that use MMFE are various but they typically model forecasts to become more accurate over time. However, Cattani and Hausman (2000) question such an assumption. With real data from companies they show that demand forecasts do not necessarily become more accurate as they are updated. This is illustrated in Fig. 1 of Cattani and Hausman (2000) at http://dx.doi.org/10.1287/msom.2.2.119.12354. As is shown in the figure, the forecasts are changing, but are not converging. That is, they do not get closer to the actual points as time goes on, a phenomenon the author call "forecast churning." They argue that such forecast churning can cause inefficiencies if the firm reacts to the wrong forecast update. Another survey study by Wacker and Hanson (1997) of large global manufacturing firms further show that forecast errors persist, however they do not create significant impact on firm competitiveness.

2.5 Incentives and Contracts in Sharing Forecast Information

But there is more story behind forecast error and forecast churning. Cohen et al. (2003) and Terwiesch et al. (2005) empirically study the evolution of forecasts based on their study of the semiconductor equipment industry. First of all, consistent with Cattani and Hausman (2000), they find that forecast accuracy does not improve over time. See below a typical picture of different forecasts shared by a major semiconductor manufacturer to one of its major suppliers, as well as the actual demand (Fig. 2.1).

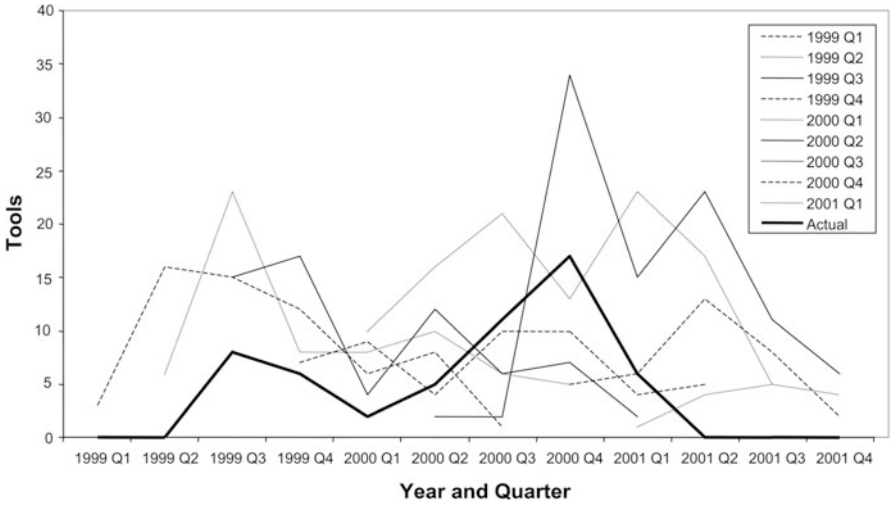

Fig. 2.1 Forecasts show a over-forecasting bias, Cohen et al. (2003) (reproduced with permission from INFORMS)

But the picture reveals something more than just random fluctuations of forecasts: the actual orders seem to be lying below most of the forecasts. In other words, the manufacturer seems to be consistently over-forecasting. Why is that? The answer to this question is the key contribution of Cohen et al. (2003). They find that the manufacturer has a strong incentive to over-forecast. The reason can be explained with a "newsvendor-type" logic: the cost of inflating forecasts and canceling is much less than the cost of truthful forecasts but having to deal with the possible supply shortage.

Speaking of incentives in information sharing in supply chains, Lee et al. (1997) provide one of the earliest academic discussions of problems related to order forecasts and their implication on supply chain coordination. They call order forecasts that are eventually cancelled "phantom orders," and see them as one of the key factors contributing to the now well-known bullwhip effect in supply chains. Given that supplier capacity may be constrained, a buyer has a strong incentive to forecast extra orders (phantom orders), especially if scarce capacity is rationed based on placed orders. Armony and Plambeck (2005) investigate how such false orders can lead a manufacturer to overestimate the demand and make faulty decisions about capacity investment. They motivate their study by citing a high-profile news story of Cisco, writing off assets worth of billions of dollars due to phantom orders placed by its suppliers.

When a supply chain party possesses private information that the other parties do not know, and given incentives that may be in place for distorting information, how to induce truth-telling in sharing forecast is an important topic. Cachon and Lariviere (2001) is one of the earliest study of incentives in information sharing using a game-theoretical approach. They formulate a capacity procurement game,

where a high-demand type customer has to dispense extra incentive as a signaling device, such as fixed payment or a large firm commitment, in order to induce the supplier to provide enough capacity for high demand. Later papers by Özer and Wei (2006) show that channel coordination is possible when combining capacity commitment contract with payback contract in the setting of Cachon and Lariviere.

Ren et al. (2010) propose a long-term perspective of this problem, where supply chain parties expect to transact repeatedly over a long horizon. They show that under some conditions supply chain parties can develop a 'harmonious' relationship where a simple wholesale price can achieve truthful information sharing and system coordination asymptotically. But can such a results be proven empirically or experimentally?

Özer et al. (2011) devise a series of clever experiments to test if such a "trustworthy" relationship can be obtained from repeated interactions. In their benchmark model they are able to replicate the over-forecasting phenomenon predicted by one-shot game-theoretical models confirming the over-forecasting bias. See the top part of Fig. 1 in Özer et al. (2011) at http://dx.doi.org/10.1287/mnsc.1110.1334.

Interestingly, as supply chain parties interact repeatedly over a longer horizon, the authors observe a continuum of trust among supply chain dyads. This result shows that in reality we may observe various degrees of supply chain coordination that are much richer than what previous theoretical model. They then fashion a parsimonious 'trust-embedded' model which fits experimental data remarkably well.

2.6 Value of Inventory Information

The advance of information technology such as RFID, Internet and cloud computing has made inventory information available and therefore relevant to supply chain management practice. But the basic information remains: "Is it helpful to know inventory information of downstream supply chain parties?"

Using a series of lab experiments mimicking supply chain environments, Croson and Donohue (2006) study the benefit of sharing inventory information in "the beer game." First, they find that decision makers consistently under-weigh the pipeline stock even when the normal operational causes (e.g., batching, price fluctuations, and demand estimation) are removed, and as a result the bullwhip effect persists. Will sharing inventory information help remove some of the variability? It turns out sharing inventory information has little effect on the orders of downstream chain members. On the positive side, inventory information seems to substantially reduce the variance of orders for upstream members.

Empirical findings related to the effect of sharing inventory information can be found in studies on supply chain coordination initiatives such as Vendor Managed Inventory (VMI), where sharing inventory information is a prerequisite. Clark and Hammond (1997) find a correlation of VMI practices with performance improvements. Kulp et al. (2004) conduct an extensive study with the food and consumer

packaged goods industry, and find that sharing retail store inventory levels and collaborative planning on replenishment practices such as VMI provide benefit to the manufacturer's profitability.

2.7 Value of Sharing Order Status Information

Does it help to know where exact an order is in a supply chain, whether it is in transit or in process? Before the advent of the Internet and sophisticated information technology such information was unobtainable. However, as technologies such as RFID and GPS systems, as well as Internet access are becoming widely available, it becomes interesting to ask what the value of having order status information is.

Theoretical research on this topic overall demonstrate that there is positive value in such type of information. For example, Gaukler et al. (2008) find that knowing how far along an outstanding order is being processed in a supply chain not only helps the retailer in deciding when to order and how much to order, but also allows the retailer to place an emergency order when it expects a delay is likely to occur. They calculate that the cost savings can be large, especially in supply chains with longer and more volatile lead times. Jain and Moinzadeh (2005) consider the value of manufacturers sharing inventory availability information with retailers. In their model a manufacturer can inform its retailer if a product will be on backorder before the retailer places its order. They find that sharing such information will actually induce the retailer to order more frequently.

Empirical studies on the benefit of sharing such information can be found in the area of collaborative planning, forecasting, and replenishment (CPFR). Yao et al. (2013) collected data on CPFR activities from Motorola and its suppliers, and find that forecast accuracy tends to improve immediately after CPFR implementation, but then the rate of improvement slows over time. Inventory levels initially increase after implementation and then begin to decrease. It seems that more empirical studies are needed to ascertain the benefit of sharing inventory status information.

2.8 Sharing Information About Product Development

Product development sits at the top of a supply chain. Therefore, it is relevant to study information sharing that is related to product development. There are two dimensions to this. The first is information sharing within the process of product development. There, the research question is how to best share information in order to come up with successful products with faster lead times. The second dimension is about the value of sharing information about product development, with other echelons of the supply chain. Below we review both areas of research.

Sharing product information is similar to sharing forecast information. In both cases, what is being shared is not-yet-finalized preliminary information.

Development teams frequently begin their work on a new product prior to receiving detailed design specifications from the customer or from adequate feedback from market research. How to utilize preliminary information is a central question. In this line of research, Loch and Terwiesch (1998) study the situation faced by a concurrent engineering team of a European auto company where an information-receiving team must decide on how to rely on the preliminary information provided by the information sender. The information receiver has an incentive to start early, but starting early means using a lower quality of information and thus has a higher chance of costly rework. Thus it faces the "Rush and be Wrong or Wait and be Late" dilemma, which is similar to the supplier's problem as described in Cohen et al. (2003).

Empirically identifying the value of sharing product development-related information is an interesting topic as firms take very different approaches in practice. Take product pre-announcement, for example. In the high-tech industry, it is well known that there are firms who never give product announcements (e.g., the famous Apple secrecy), and there are others who tend to pre-announce their pipeline products well ahead of time (e.g., Microsoft). What is the impact on their competitors and on their supply chains? Bayus et al. (2001) analyze data on product pre-announcement in software development industry (also called "vaporware"), and find that software development process is inherently uncertain and delays are inevitable. Moreover, smaller firms tend to pre-announce products strategically in response to product development status of larger competitors. In a supply chain context, research seems to favor sharing product development information with their supply chain partners. Kulp et al. (2004) collect data from the food and consumer packaged goods industry, and find that when manufacturers work closely with their retailers by sharing product development-related information, they are more likely to have higher profit margins.

2.9 Sharing Inaccurate Information

Most of the supply chain modeling work assume that information shared in supply chains is accurate. But to what extent is that true? Empirical evidence suggests that such an assumption needs to be reevaluated. Raman et al. (2001) find that data inaccuracy persists in the retailing inventory, which results in substantial operational inefficiency and profit loss. DeHoratius and Raman (2008) study inventory record accuracy with one nationwide retailer, and find that 65 % of the records have some forms of inaccuracy.

Recent analytical research has taken notice, and has begun to address this issue (e.g., Kok and Shang 2007). Lee and Özer (2007) study the value of RFID technology in improving information accuracy. They distinguish inventory records from actual inventory, and attribute inventory inaccuracy to two causes: inventory misplacement, and transaction errors. They also show that RFID technologies allow for better control and can reduce inventory-related costs.

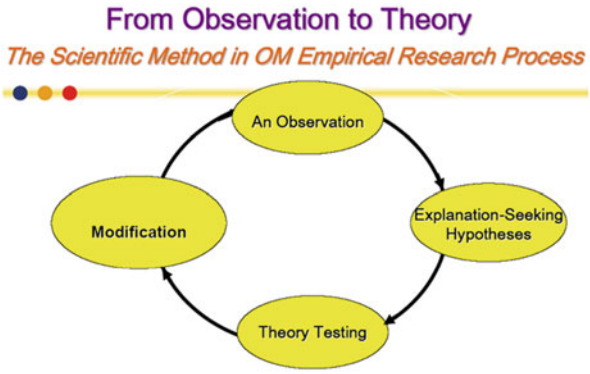

Fig. 2.2 Presentation slide from Fisher M (2005) What can we learn about research style from physics, medicine and finance? Plenary speech, POMS Conference 2005, Chicago

2.10 Summary

Supply chain innovation constantly brings about new questions and challenges. While in the area of operations management and supply chain management there is an overall healthy balance of theoretical and empirical research, we argue that the area could benefit from more empirical research.

In his keynote address at the 2005 Production and Operations Management Society (POMS) annual conference, Professor Marshall Fisher delineates an empirical research cycle for the OM research community (Fig. 2.2).

With more empirical research helping us identifying and answering questions from the real world, we will be able to deepen our knowledge body, better guide business practice, and also spur further analytical research.

We are also in need of empirical research that directs test and validate the theoretical modeling work that has been in blossom in recent decades. For example, as we mentioned earlier, there has been few empirical or experimental studies that aim to direct validate the various models measuring the value of demand information. It will be immensely gratifying if more researchers could step up and take on these important challenges and contribute to the larger OM community.

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